Title of Investigation:

PN Code Modulated Fiber Lasers for Pushbroom Mapping Altimetry from Or

Principal Investigator:

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Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$61,000

Funding Authorized for FY 2004:

$61,000

Actual or Expected Expenditure of FY 2004 Funding:

Small purchases (components) $10,000; mechanical lab support, $5,000; and programming support, $5,000

Status of Investigation at End of FY 2004:

Requested extension to complete year 2 of 2-year plan

Expected Completion Date:

September 2005

Purpose of Investigation:

Current satellite-based laser altimeters can measure surface heights only along a single profile line under the satellite orbit. However, many investigations need to measure surface-height distributions in a swath and not just along a narrow profiling track. Generally, a need exists to expand the capability of laser altimetry to make full two-dimensional maps of surface height from orbit. We propose to investigate the use of fiber laser-based altimetry configured into a novel swath-mapping pushbroom laser altimeter. A passive pushbroom sensor for a satellite uses an array of passive sensor elements, which view a planet's surface in a direction across the orbital track. The orbital motion of the satellite then pushes the sensor-measurement line along the ground track of the satellite, like a broom sweeping across a floor. Our approach investigates this strategy for the first time.

Approach:

In our approach, each fiber laser and photon-counting detector pair forms one line of the "altimeter pushbroom," a 5- to 10-meter-wide laser-profiling track. By using many of these pairs displaced in a line across the track, altimetry measurements can be made simultaneously over kilometer(s)-wide pushbroom swath. The advantages of this approach are: 1) The architecture is parallel and scales to very wide swaths; 2) It is power and photon efficient; 3) It is based on a strong growing industrial base; 4) It is fault tolerant. A failure of a single laser or detector only drops a single measurement line within the much wider mapping swath; and 5) It is flexible—both the pseudo-noise (PN) code rate and receiver integration time can be programmed on-orbit to optimize measurement performance for different Earth surface types—for example, vegetation versus ice-sheet measurements.

The key is developing an approach for an efficient, scalable, and reliable single-measurement line. We chose a modular technique based on fiber-laser technology, digital modulation, and photon-counting detectors. Our transmitter is seeded with a stable, single-frequency diode laser externally modulated by a digital PN code and scaled to Watt-levels by a fiber amplifier. Fiber amplifiers are attractive for space use because they are reliable, currently in mass production for the fiber telecommunications industry, rugged and compact, have few parts, and have electrical efficiencies of greater than 20%. Lucent has recently space qualified an Erbium-Doped Fiber Amplifier (EDFA) for a Department of Defense (DoD) space communications link. In addition, all optical signals are contained within optical fibers, which can be routed like electrical cables. This eliminates the need for heavy mirrors and a large optical bench.

The fiber laser's output is optically modulated at 1 Gbit/sec rate by a PN code. This code impresses a digital ranging pattern on the power of the optical carrier. The delay of the ranging code (and thus the range) can be unambiguously recovered in the receiver to yield range measurements with greater than 15-cm precision. This is done by first time sorting and accumulating (i.e., histogramming) the detected photon counts into time (i.e., range) bins corresponding to positions in the transmitted code, and then after integration, by cross correlating the accumulated photon histogram against the transmitted code. For example, 1.5-millisecond integration time can be used to obtain 700-Hz measurement rate for 10 meters along track resolution. This measurement approach is similar to the way PN code modulation is used with radio-frequency (RF) carriers for the Global Positioning System (GPS). In 1992, Rall and Abshire also demonstrated a PN-code modulated atmospheric lidar, which used diode lasers modulated with 2 MHz PN codes, and measured atmospheric backscatter profiles with 75 m vertical resolution.

Accomplishments to Date:

We are making good progress and this approach still appears very promising. We have purchased and assembled the key hardware items and have assembled them in our laboratory in Building 33. We have demonstrated clean amplification of the PN-encoded, intensity-modulated seed at 100- and 500-MHz rates by the 1570 nm fiber amplifier. We also have demonstrated a detection and correlation receiver in the laboratory. We have successfully demonstrated PN-coded ranging using a fiber-laser transmitter at 1570 nm and an analog detector at the receiver, to a cooperative target over a 206 m horizontal path from our laboratory. We have purchased photon-counting electronics, capable of time binning photons at higher speeds. We also have purchased higher-bandwidth components for faster laser modulation, which will increase our accuracy and precision.

We also have considered using this technique with continuous wave (CW) ytterbium-doped (Yb) fiber amplifiers operating near 1060 nm. The potential advantages are higher laser efficiency compared with erbium-doped fiber amplifiers, while operating at a wavelength where photon-counting detectors are available. In parallel, we also organized work on a related Earth-mapping mission concept called DELI. We convened workshops and collected and compiled similar requirements for high-spatial resolution, space-lidar measurements for ice sheet topography, topography, vegetation height mapping, and hydrology science areas. This mapping approach is a strong candidate for DELI and similar planetary missions.

We report here some initial results from evaluating digitally modulated CW lasers and photon-counting detectors for altimetry measurements. The configuration is shown in Figure 1. We consider a configuration with transmitter with a stable single-frequency seed laser, whose output is intensity modulated by a digital PN sequence. This signal is amplified by a fiber amplifier, collimated, and directed to nadir. The photons scattered from the surface are collected by the receiver telescope, passed through a band-pass filter and illuminate a photon-counting detector. The resulting counts are accumulated (histogrammed) synchronously with the transmitted code. After the needed integration time, the histogram is cross-correlated with the transmit code to yield the backscatter versus range profile, i.e., the altimeter echo waveform. If the code and histogram use a 1 Gbit/sec modulation rate, the resolution of the echo waveform will be 15 cm/bin, equivalent to the resolution of the GLAS receiver.

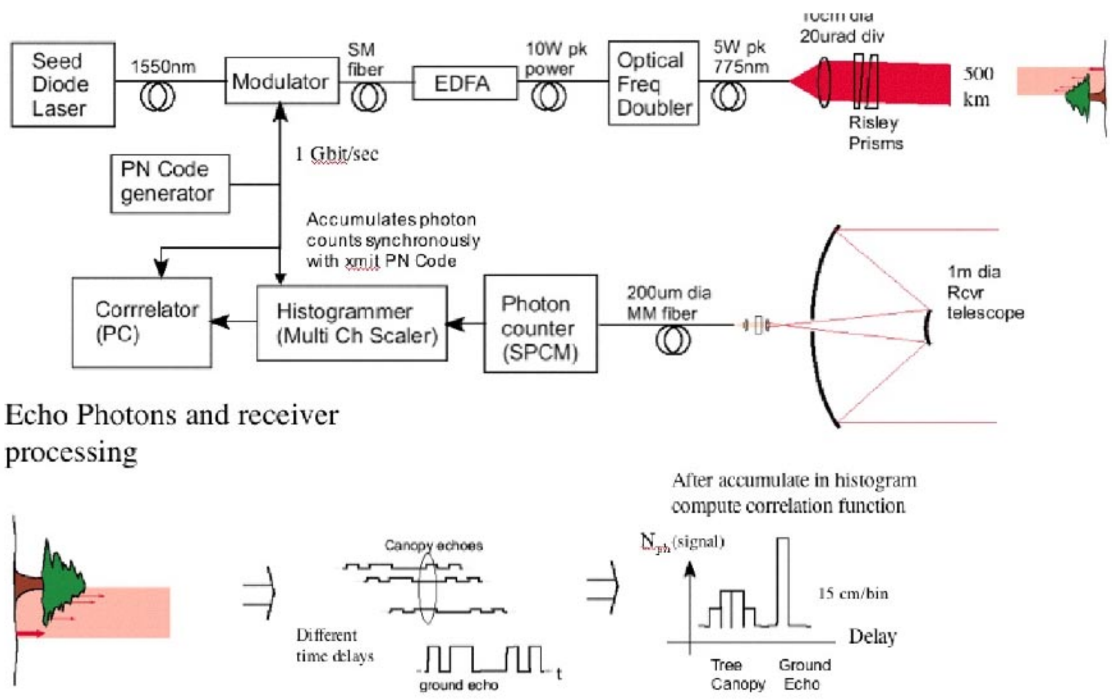

Figure 1. Block diagram of a single-measurement channel for a pushbroom laser altimeter using pseudo-noise modulation and photon-counting detection. A common receiver telescope is used with many of these measurement channels in parallel (i.e.. with their measurements distributed cross-track). Each laser/detector/histogram subsystem makes up one profiling measurement line of the push-broom measurement swath.

We have prepared a model and calculated the performance of a possible future space-based, PN-coded altimeter that uses a photon-counting detector. The primary sources of noise for the altimetry measurement are the signal-shot noise in the extended backscatter signal, plus solar background and dark counts from the photomultiplier detector. Some results from calculations are shown in Figure 2. These were based on a 500-km orbit, 70% atmospheric transmission, and 10-m diameter laser spots on an ice surface with 3° slope. The altimeter was assumed to use a Yb-fiber amplifier at 1060 nm, modulated with a 500 Mbit/sec PN code, a 1-m diameter receiver telescope, and a 5% quantum efficiency photomultiplier (PMT) detector with 1-KHz background rate. The receiver integrates for 1.5 milliseconds per measurement. The detection probability and range errors are shown for day and night. Detection probabilities of greater than 90% and ranging error of less than 10 cm can be attained with about 6 watts peak laser power.

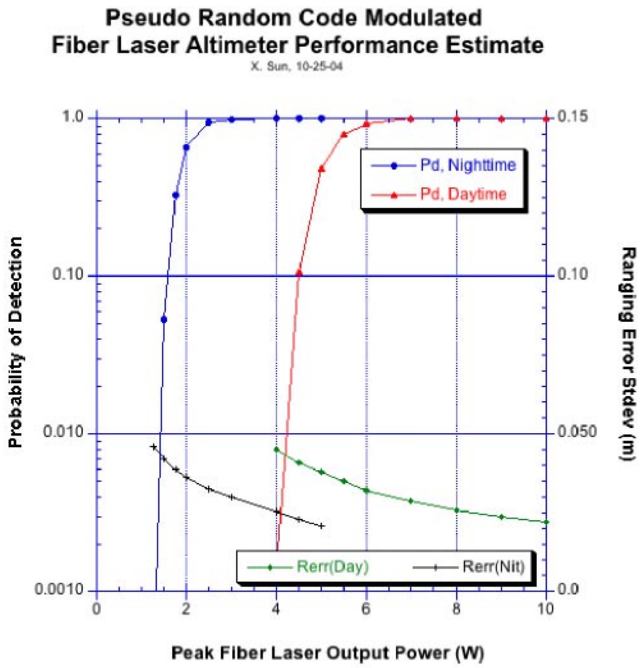

Figure 2. Calculated PN-coded laser altimeter performance measuring to an ice sheet surface from 500 km altitude

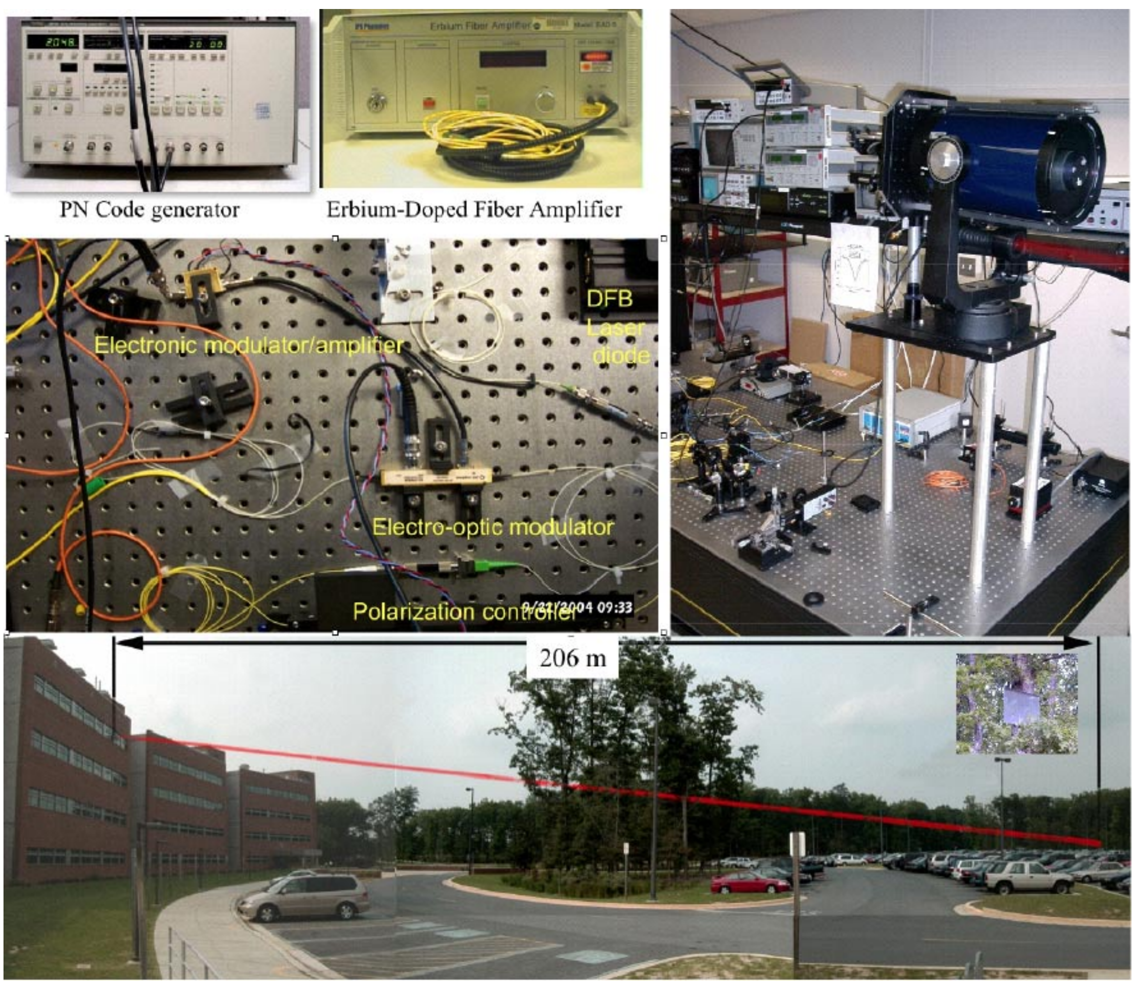

Figure 3. Photo shows the laboratory breadboard setup in Building 33. Initial experiments were at 1570 nm, utilizing components from prior work. The telescope is aimed at a target out the window, about 4 m above ground, across the 206-meter-long test path.

We also have demonstrated a practical PN-coded altimetry measurement using the configuration shown in Figure 3. These experiments used a single frequency 1570-nm diode laser, whose output is modulated by an external Mach-Zhender modulator with a 127-bit PN code at 100 Mbits/sec, amplified by an EDFA to about 1 watt of optical power, then transmitted over a 206-meter-long horizontal path to a cooperative target. The backscatter was collected with a 20-cm diameter telescope and the echo signal detected with a fiber-coupled InGaAs analog detector. The detected analog signal was digitized and the waveform was cross-correlated with the transmitted code. The measurements from the experiment are shown in Figure 4. The cross correlation plot on the right shows the well-defined round-trip correlation peak at 412 m for the optical path of 206 m.

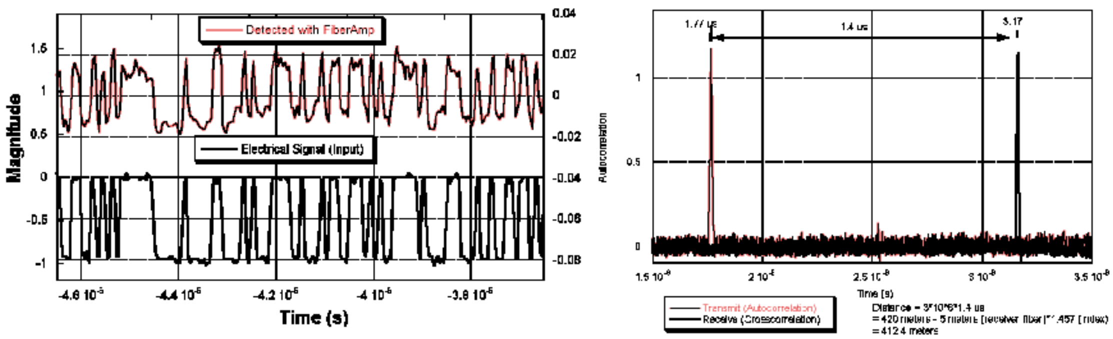

Figure 4. Transmit and time-shifted return echo using a 100 Mbit/sec PN-coded seeded laser, amplified and an analog detector. The cross-correlation peaks (right) correspond to the optical round-trip travel time to a target at 206 m away.

We performed a second experiment in the laboratory to explore the low-signal detection performance. In it, we modulated only the diode laser signal, which was then attenuated and fiber coupled into an infrared photon-counting PMT detector (Hamamatsu Model H9175). For these experiments, the detected signal count rate was about 120 KHz, and the background only count rate was about 100 KHz. The results show the technique can measure at low signals levels and the high rates (700 Hz) needed from space. It also shows the measurement statistics scale as expected at low signal levels.

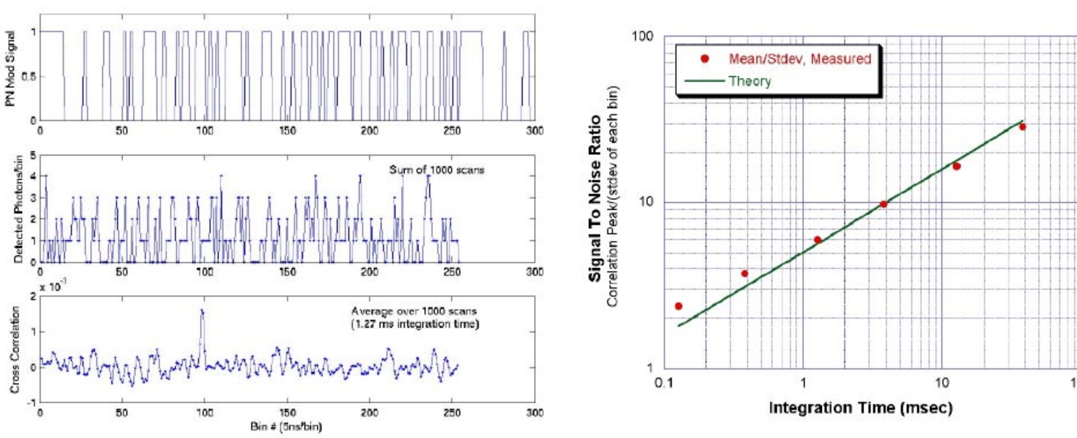

Figure 5. Left, from top to bottom, reference PN waveform, detected photon-counting histogram accumulated in 1.27 millisecond integration time and the cross correlation, which clearly shows the expected range spike with an offset of about 100 range bins. Right: the SNR as function of receiver (i.e., histogram) integration time. The SNR of the correlation peak varies as (integration

Publications and Conference Presentations:

We have submitted a paper, which will be presented at the Optical Society of America Conference on Lasers and Electro-Optics 2005 (CLEO'05) in Baltimore, Maryland. We plan to submit an article to a journal describing the technique and our initial results.

Planned Future Work:

Our plans for FY 2005 are to

- Select optimum wavelength technology (laser, amplifier, detector) for second year;
- Demonstrate higher speed modulation of fiber amplifier output (> 400 Mbit/sec) ;
- Purchase optimized modulators for selected wavelength;
- Demonstrate sensitive (fW) photon-counting detection of modulated PN codes;
- Demonstrate PN ranging at selected wavelength with above components;
- Compare performance of approach and technology with others for laser altimetry;
- Demonstrate detection from non-cooperative target and changing range to target; and
- Demonstrate end-to-end system with photon-counting detector

Summary:

There is considerable need for swath-mapping, laser-altimetry measurements from space. However, these measurements from space are very demanding compared with the laser-profiling measurements used to date. We are developing a new technique to use modulated, long-lifetime, CW fiber lasers coupled with photon-counting detectors to enable high-resolution mapping altimetry. The technique is flexible and can use different codes on orbit for different surfaces and appears viable for different wavelength bands.

Another advantage to this technique is that it allows NASA the opportunity to “leverage in” more highly developed technology than is possible with the diode-pumped Nd:YAG currently used in profiling altimeters. The CW fiber lasers we use have benefited from substantial industrial investment in their key components and in their reliability. The photon-counting detectors are available commercially. Ongoing programs, such as NASA’s Mars Laser Communication Demonstrator (MLCD), are working to further improve detector sensitivity and lifetime.

This approach has considerable risks, however. Because several aspects of the measurement approach are new, they have never been proposed or carried out before. Our criteria for success include showing that the technique makes the needed measurements and that the approach is practical for space use. Based on our initial results, we have already proposed this technique for an ice sheet-mapping altimeter for the recent NASA Earth-Sun System Technology Office (ESTO) IIP Research Announcement.